

UTILITY APPLICATION

OF

**MARTIN C. BAKER, SANTOSH K. DAS, RICHARD
F. HARAZ, WILLIAM F. HEHMANN, VINCENT J.
PAPOTTO, FEDERICO RENTERIA, and GARY
WINCHESTER**

FOR

UNITED STATES PATENT

ON

**HAND HELD POWDER-FED LASER FUSION
WELDING TORCH**

Honeywell Docket No.: H0002114D2—1060
Sheets of Drawings: 5

FOR
HONEYWELL INTERNATIONAL, INC.
Law Dept. AB2
P.O. Box 2245
Morristown, New Jersey 07962
Customer No.: 00128

HAND HELD POWDER-FED LASER FUSION WELDING TORCH

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a divisional of Application Serial No. 10/071,025 filed on February 8, 2002, now U.S. Patent No. 6,593,540 and Application Serial No. filed on June 12, 2003.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to laser fusion welding and more particularly to a hand held powder-fed laser fusion welding torch.

Description of the Related Art

In general, the surface of a metallic article may be welded and/or alloyed by the simultaneous and cooperative operation of a laser beam and an alloy powder stream. To accomplish this, systems exist that have a laser source and focusing apparatus, with a powder delivery apparatus provided as part of an integral package. The laser beam melts a relatively small area at the surface of the article, and a controlled volume of alloying particles are delivered into the melt pool via the powder flow stream.

In laser fusion welding, an article of metal or other material may have the surface thereof alloyed, or otherwise treated, by the simultaneous and cooperative operation of a laser beam with an alloy powder. Typically, the laser beam melts a relatively small volume of the outer surface

of the article and the powder system delivers a controlled volume of alloying particles into this molten volume. The alloying particles become dispersed throughout this volume and therewith alter, complement, or add to the composition of the outer layer in a controllable way. Removal of the beam, such as by advancement of the workpiece relative to the focal point of the beam, causes the molten volume to be rapidly chilled. The chilling occurs so rapidly that the volume retains the characteristics of the molten mix.

As an example, gas turbine engines, such as those utilized with jet aircraft, are being designed with ever increasing performance requirements. One element of the engine which has been receiving attention is the seal created between the outer periphery of the rapidly rotating blades and the surrounding housing. Another element subject to attention is the turbine nozzle system in jet engines.

The owner of the present invention, Honeywell International, Inc., often repairs turbine nozzles with a process called JetFix. The JetFix process uses steps as follows: chemically and mechanically stripping the outer aluminide coating, welding the cracks, thermally shocking the welds (to form micro cracks), fluoride ion cleaning of the cracks, (to remove oxides), applying a JetFix braze alloy, vacuum furnace brazing, blending brazing, re-application of aluminide coating, and effective flow area check.

Laser powder fusion (LPF) technology has been in use for the past twelve years and has demonstrated the benefits of small heat affected zones on turbine airfoils. Some repair facilities, such as those at Honeywell International Inc., have successfully repaired over 500,000 airfoils which have subsequently accumulated over 10 million flight hours. However, commercially available LPF machines are relatively large and usually run along pre-programmed paths for the repair of a specific part. Thus, one limitation of LPF is the inability of the user to manipulate the

laser torch in a custom manner during the repair process as the weld occurs. Accordingly, there is a need for an LPF apparatus that can allow the user to tailor the weld and welding process to the workpiece as the laser is being operated. The present invention satisfies this need.

SUMMARY OF THE INVENTION

The present invention provides a hand-held powder-fed laser fusion welding torch that allows customized welding by delivery of laser light onto a stream of welding fusion powder. The ability to provide such a compact laser welding system increases convenience and flexibility, enabling the welder to create or repair objects with greater skill, flexibility, and efficiency.

Worn or damaged metal parts and assemblies may be repaired or dimensionally restored through high power laser processing with a laser source of sufficient intensity to melt the metal surface while a metallic filler in the form of a powder, wire or rod is introduced into the melt pool. Metallic precursors in a liquid or semi-liquid form may also be applied to the surface, allowed to dry, and then laser processed. In situations where the work surface is not accessible by conventional workstation type of laser powder metal fusion equipment, a compact hand-held torch is preferred. Other cases may involve the repair of parts having irregular and random cracks or damage not otherwise repairable by robotic or programmable workstations. In order to perform repairs of this type, a portable, flexible delivery system is required for both laser as well as the metal filler. This invention provides for these needs through the integration of laser beam and metal powder delivery components into a single compact hand-held unit. The laser source may be a continuous wave Nd:YAG laser.

In one embodiment, the hand held laser includes a body and a nozzle assembly mounted on the body, with the nozzle assembly defining a central nozzle aperture through which gas and

light including laser light may pass. The nozzle defines first and second powder flow channels aligned with a working focal point adjacent the central nozzle aperture. Fusion powder may be transmitted through the first and second powder flow channels for fusing by laser light transmitted through the central nozzle aperture.

In another embodiment, a method is provided to manually laser powder fusion weld a workpiece in order to effect construction and/or repair. A hand held powder-fed laser fusion welding torch is provided that may be manually operated. In such manual operation, the torch generally enjoys significant degrees of spatial freedom so that the welder may dispose the torch in a variety and number of easily-achieved positions. In this way, the welder may conform his activities to the needs at hand and is preferably not limited by physical constraints of the laser torch.

Other features and advantages of the present invention will become apparent from the following description of the preferred embodiment(s), taken in conjunction with the accompanying drawings, which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a right side perspective and exploded view of the hand held powder-fed laser fusion welding torch assembly according to the present invention.

Figure 2 is a right side cross-sectional view of the hand held powder-fed laser fusion welding torch of Figure 1 with an optical collimator and without the nozzle gas cover.

Figure 3 is a right side top and partial cross-sectional view of the hand held powder-fed laser fusion welding torch of Figure 1 taken along line 3-3 of Figure 8.

Figure 4 is a right side perspective view of the hand held powder-fed laser fusion welding torch of Figure 1 shown as assembled.

Figure 5 is a status/control diagram for the proximity sensor system.

Figure 6 is a right side plan view of the hand held powder-fed laser fusion welding torch of Figure 1.

Figure 7 is a right side cross-sectional view of the hand held powder-fed laser fusion welding torch of Figure 1 taken along line 7-7 of Figure 6.

Figure 8 is a rear plan view of the hand held powder-fed laser fusion welding torch of Figure 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

The detailed description set forth below in connection with the appended drawings is intended as a description of presently-preferred embodiments of the invention and is not intended to represent the only forms in which the present invention may be constructed and/or utilized. The description sets forth the functions and the sequence of steps for constructing and operating the invention in connection with the illustrated embodiments. However, it is to be understood that the same or equivalent functions and sequences may be accomplished by different embodiments that are also intended to be encompassed within the spirit and scope of the invention.

An alternative and less costly or intrusive process uses a hand-held laser powder fusion (LPF) torch could repair the turbine nozzle cracks by local removal of the coating and crack, laser powder fusion welding, blending and local touch up of the aluminide coating. The advantages of LPF welding are the low heat input and resultant heat affected zone which allows welding on turbine nozzles where previously it was not permitted.

Worn or damaged metal parts and assemblies may be repaired or dimensionally restored through high power laser processing with a laser source of sufficient intensity to melt the metal

surface while a metallic filler in the form of a powder, wire or rod is introduced into the melt pool. Metallic precursors in a liquid or semi-liquid form may also be applied to the surface, allowed to dry, and then laser processed. In situations where the work surface is not accessible by conventional workstation type of laser powder metal fusion equipment, a compact hand-held torch is preferred. Other cases may involve the repair of parts having irregular and random cracks or damage not otherwise repairable by robotic or programmable workstations. In order to perform repairs of this type, a portable, flexible delivery system is required for both laser as well as the metal filler. This invention provides for these needs through the integration of laser beam and metal powder delivery components into a single compact hand-held unit. Currently, the preferred laser source is a continuous wave Nd:YAG laser, of medium to high power (e.g., 600 - 1000 watts), capable of melting a variety of metals when focused to a spot at the work surface. In a YAG (Nd:YAG) laser, the amplifying medium is a rod of yttrium aluminum garnet (YAG) containing ions of the lanthanide metal neodymium (Nd). Other laser and/or powder feed sources may be used, as required for particular applications.

The Nd:YAG laser is used, because:

- 1) The one point zero six micrometer (1.06 μm) fundamental characteristic wavelength of Nd:YAG lasers is readily transmitted through flexible silica fiber optic cables;
- 2) The beam spatial characteristics are favorable for focusing by simple lenses to produce spot sizes on the order of one millimeter (1 mm) diameter with sufficient power density and uniformity required to melt metal alloys commonly used in jet engine applications; and
- 3) The Nd:YAG laser fundamental wavelength is readily absorbed by the

host metal, enabling melting of the metal at lower laser power settings.

A fiber optic delivery system permits the laser source to be located remotely from the hand-held laser welding torch, as required for hand manipulation.

The laser torch is comprised of an optical system to focus the laser beam onto the workpiece, and an integral metal powder delivery nozzle to deposit metal alloy powder into the metal melt pool produced by the focused laser radiation. The torch assembly is optically coupled to the laser source through the flexible fiber optic light cable. Laser energy emitted by the source is transmitted through the fiber cable to collimating and focusing optics contained within the torch housing. The focal spot size is selected to produce the desired melting of the base material at the lowest possible laser output power. Melt pool diameter, depth of penetration, heat affected zone (HAZ) dimensions and weld rate are closely related to the laser focal spot diameter and total laser output power. Good results have been achieved with one millimeter (1 mm) diameter spot sizes with six hundred watts (600 W) of laser output power. Variations in the base metal characteristics and desired weld rate may require different spot size and laser power settings. The spot size and working focal distance are adjusted by choosing different combinations of collimating and focusing lenses. The torch assembly can be disassembled in sections to facilitate lens changes. Laser power is adjusted by varying the power output setting of the laser source.

Metal powder is introduced into the weld zone through one or more nozzles contained within or attached to the laser torch. In one embodiment, the powder nozzles are coaxial with the optical beam path. This arrangement is more compact and provides better access to the workpiece than an offset nozzle design. Greater flexibility in manipulating the torch is also provided by the coaxial design. A separate, hand-held off-axis powder delivery nozzle or nozzles, not attached to the laser torch, may also be employed. Size, weight, balance and

ergonomic features are incorporated to provide for manual control and manipulation. An integrated, optionally or selectably removable, handle is included for enhanced controllability. Removable, interchangeable powder delivery nozzle tips may accommodate working distances ranging from one-quarter inch to 3 inches (0.25" to 3").

Metal powder is metered at a preset flow rate from a remote feeder/hopper unit to the nozzle assembly via flexible tubing. The flow can be started and stopped by the operator through a remote control. One or more integral safety sensor devices may actively monitor the proximity and orientation of the torch with respect to the workpiece during operation, thus preventing accidental or unintentional activation.

An alternate design may have one or more offset nozzles attached to the optical focusing assembly. The angle and relationship of the offset nozzles may be adjusted to provide the desired placement of metal powder with respect to the laser focal spot.

As shown in Figure 1, the Hand Held Powder-Fed Laser Fusion Welding Torch **100** has an optional handle **102** to which a body **104** is attached by a pin, screw, bolt, rivet **106**, or other fastener which passes through the upper portion **108** of the handle **102**. The upper part **108** of the handle **102** is constructed so as to accommodate the cylindrical configuration of the body **104**.

The body **104** has a lens protector to its rear as described in more detail below and provides an interchangeable element to which the nozzle **140** and the beam delivery assembly **130** as well as the handle **102** may be attached in an interchangeable and convenient fashion. The upper aperture **120** serves as an inlet through which bleed gas may flow into the torch **100** and provide a generally inert environment through which the laser light may travel and in order to prevent oxidation or other chemical reaction by the laser light. Additionally, the inert gas may

provide an optically predictable environment through which the laser light may travel. Additionally, the bleed gas flowing through the upper aperture **120** serves to prevent and inhibit the entry of a dust or other particulate matter into the torch **100**, particularly the nozzle **140** or other confines thereof.

The inert gas may be the same as that described in more detail below with respect to the nozzle gas cover **170** and generally encompasses most or all inert gases depending on the applications to which the torch **100** is put. Such inert gases include helium, argon, and nitrogen. While the flow rate for the gas flowing through the nozzle gas cover **170** is on the order of liters per minute (l/m), the volume of gas flowing through the upper aperture **120** is generally on the order of cubic feet per hour, for example four cubic feet per hour.

The handle **102** may be detached from the body **104** in order to create a handle less torch **100**. Under any circumstances, the operator of the torch must normally use welding gloves or the like in order to protect his or her hand from ejecta and other material from the welding site. This ejecta from the welding site is one of the motivations for the bleed gas flowing through the upper aperture **120**. The bleed gas generally inhibits or prevents the entry of such ejector back into the torch **100**.

The lower body aperture **122** serves to accommodate the pin or screw **106**, which passes through both the handle **102** and the body **104** in order to attach the body **104** to the handle **102**.

The body **104** has threaded rear **124** and front **126** flanges. The flange may be threaded for attachment. The rear flange allows for more secure fixation of the beam delivery assembly **130**, which is shown in cross-sectional detail in Figure 2. The front flange **126** serves to allow better fixed engagement between the body **104** and the nozzle **140**. The adapter body **104** may have other means by which it can be attached to the different elements of the torch.

The size and the shape or the length and diameter of the adapter body **104**, may be sized and/or dimensioned according to the optical or other characteristics desired in the laser torch **100**. If additional length is needed to accommodate the nozzle **140** or other structure, the adapter body **104** may be lengthened in order to accommodate a more distant focal length, for example. Additionally, the diameter of the adapter body **104** may also be adjusted according to operating characteristics of the torch **100**.

Furthermore, in an alternative embodiment, the torch **100** may be constructed in a combined fashion so that all components are in a single integrated unit. However, this static configuration does not lend itself to adaptability that may be necessary for different operations or tasks. Consequently, it is seen as being more advantageous to provide a component-element structure to the laser torch **100** so that different operating elements may be dismantled or disconnected from the others in order to provide easier maintenance, interchangeability, and adjustability. Generally, with the optical characteristics, the gas flow characteristics, and the powder flow characteristics, it is not possible to provide immediate selectable adjustment for these different facets or operations. Consequently, separate parts must generally be independently machined in order to provide the structure or architecture necessary for providing different operating characteristics. This includes, for example, the diameter of the adapter body **104** or the angle at which the powder flows into and through the nozzle **140**.

The nozzle **140** is generally hollow in its interior mediating the wide opening at its rear **142** to the narrow front opening **144**. The rear portion of the nozzle **140** is generally cylindrical in nature, while the front portion is generally frustro-conic with a flat front face **146**.

The face **146** of the nozzle **140** is perforated by four powder flow apertures **148**. The powder flow apertures **148** travel backwards through the body of the nozzle **140** until exiting out

the cylindrical rear portion at rear powder flow apertures **150**. As shown in Figure 3, the powder flow channel **152** intermediating the distance between the rear **150** and front **148** powder flow openings is initially cylindrical and then tapers to mediate the narrowing diameter between that of the wider rear portion of the channel **152** to the narrow front diameter until the gas channel exits out through the front powder flow aperture **148** and the face **146**.

Each powder flow channel has inserted into its rear portion through the rear powder flow aperture **150** a powder flow tube **160** that may be made of copper. The powder flow tubes **160** are introduced into the powder flow channel **152** through the rear powder flow apertures **150** in order to provide means of connection for powder flow lines (not shown) that supply fusion powder to the welding torch **100** via the powder's forced exit out of the front apertures **148**. The powder flow tubes **160** converge to a powder feed focal point which allows the converging powder flow streams to mix, preferably outside the nozzle gas cover **170**.

Also shown in the nozzle **140** is one of two connection holes **166** that allow a pin, rivet, screw or button to secure the nozzle gas cover **170** to the nozzle **140**.

The nozzle gas cover **170** is generally frustro-conic in shape having a cylindrical rear margin **172** that is dominated by the front frustro-conic section **174**. The front section is truncated and has a central front aperture **176** surrounded by a flat toroidal section **178** of the interior. The interior of the nozzle gas cover **170** is generally hollow in order to accommodate the front frustro-conic section **184** of the nozzle **140**.

Along the rear cylindrical margin **172** are intruding indentations **180**, which serve to accommodate the protruding rear ends of the powder flow tubes **160** as they project out from the powder flow channels **152**.

Generally, there is a snug fit between the margin **172** of the nozzle gas cover **170** and the

area adjacent the rear powder channel apertures **150** in the area just before the front tapered frustro-conic portion **184** of the nozzle **140**, where the transition occurs between the cylindrical section and the tapered section. This helps to provide a rear seal between the nozzle **140** and the nozzle gas cover **170**.

The nozzle **140** and the nozzle gas cover **170** are slightly offset and spaced apart to allow gas flow between the exterior of the front section **184** of the nozzle **140** and the interior of the front frustro-conic section **174** of the nozzle gas cover **170**. As shown in Figure 3, the front aperture **176** of the nozzle gas cover **170** is also spaced apart from the nozzle face **146** in order to provide a plenum area **186** into which gas may be introduced as described in more detail below.

The nozzle gas cover **170** has a gas aperture **190** into which fits a male-to-female right angle pipe adapter **192**. A barb-to-pipe conduit **194** fits into the female section of the male-to-female adapter **192** which in turn fits into the gas aperture **190** at the male end **196** of the adapter **192**.

Left or right fasteners such as pins, screws, bolts or rivets **198** fit into apertures **200** oppositely opposed on the rear cylindrical margin **172** and pass into the attachment holes **166** in the nozzle **140** to attach the nozzle gas cover **170** to the nozzle **140**.

The gas cover **170** and accompanying inert gas structures may be omitted when the torch **100** is used in an inert environment such as a welding box, glove box or the like. Additionally, circumstances where a relatively clean vacuum is available (as in orbit) may allow the omission of the gas cover **170**. Under such circumstances, the sensor probe **220**, if any, should be attached to the nozzle **140** or other torch structure.

Additionally, a power connector **210** is attached to the nozzle gas cover **170** by one of the pins **198**. As shown in Figure 1, the pin or screw **198** attaching the power connector **210** to the

gas nozzle cover **170** is the left pin or screw **198**. The power connector **210** has attached to it a power connector clamp **212**, which is held in place by a screw or bolt **214**. The screw **214** additionally holds in place a proximity switch probe **220**, which serves to detect the presence of a welding object or workpiece in front of the operating front apertures **144**, **176** of the nozzle **140** and nozzle gas cover **170**, respectively.

The proximity probe **220** may be spring biased so that the extending proximity switch **222** is biased forwardly outwardly from the proximity holder sleeve **224**. The probe **220** is held in connection to the power connector **210** by the power connector clamp **212** and the connector screw or bolt **214**. The workpiece or object will overcome the spring biasing of the proximity switch forcing it to travel into the proximity holder sleeve **224** and thus activating or enabling activation of a power connection for the laser welding torch **100**. The entirety of the welding torch **100** is shown assembled in Figure 4.

Figure 2 shows the laser torch **100** with the attached optical beam delivery assembly **130**. The optical beam delivery assembly **130** serves to take incoming laser light **250** and focus it immediately in front of the front aperture **176** of the nozzle gas cover **170**. The optical beam delivery assembly **130** is generally made of optically inert material so that it will not be affected by laser light or the like. The optical beam delivery assembly **130** receives the laser light **250** and initially passes the light through a first collimator. The optical beam delivery assembly **130** has a first focusing lens or collimator **252**, which may be a 60 mm collimator. The first collimator **252** generally takes the incoming laser light and refracts it so that it travels parallel to the interior and generally cylindrical inner surface of the optical collimator **130**. The parallel-traveling light then shines upon a focal lens **254**, which may be a 90 mm focal lens. The focal lens **254** then focuses the parallel-traveling light to a point immediately in front of the front

aperture **176** of the nozzle gas cover **170**.

The first collimator **252** and the focal lens **254** are spaced inside the optical collimator **130** so as to effectively provide light gathering and focusing qualities with the first collimator **252** generally spaced away from the incoming laser light **250**, at a distance approximately equal to the focal length of the first collimator lens **252**. The focal lens **254** is then located near the end of the optical beam delivery assembly **130** opposite that of the incoming laser light **250**. As the focal lens **254** is protected by a lens protector **256**, it is spaced apart from the light-exiting end **258** of the optical collimator **130**.

Note should be taken that the beam delivery assembly **130** with its optimal collimating and focusing properties can serve to focus the focal point of the laser light at, beyond, or before the focal point of the powder flow and that these two focal points may be disposed selectively with respect to the end of the nozzle **140**. Under certain circumstances, it may be more advantageous to provide different focal points for the laser light and the powder flow. Generally, these focal points would be collinear with the major axis of the laser torch **100**. However, the present invention could provide alternative embodiments where such focal points are not collinear.

In the most preferred embodiment, no dispersion or absorption of the incoming laser light **250** occurs throughout the optical collimator **130** or the welding torch **100** in order to provide higher efficiency and so that as much as the incoming laser light **250** is focused upon the working focal point **270**. Minimal dispersion of the laser light is desired most as the most energy generated and imparted to the laser light is then delivered to the welding site.

Preferably, only the incoming fusion powder traveling through the powder flow tubes **160** and the powder flow channels **152** obstructs or occludes the focused laser light **250** upon

exiting the nozzle. The powder flow tubes **160** and powder flow channels **152** share the same nominal working focal point **270** as the laser light **250**. The exact location of the laser light and powder flow focal points can be adjusted independently in order to optimize the laser and powder interaction characteristics. The energy of the laser light is then focused upon the fusion powder and whatever working surface is set before the open front end **176** and the nozzle gas cover **170**.

To provide for such independent adjustment of the laser and powder, the body **104** of the torch **100** may be interchangeable and provide a selectable variety of diameters and lengths as appropriate or useful for the welding activities, as indicated above.

Additionally, in order to provide for higher transmission of the laser light, anti reflection coating may be present on the lenses through which the laser light **250** passes. Furthermore, the focusing lens **254** may be subject to possible threaded adjustment so that the focal point of the laser light may be adjusted manually and spontaneously by the welder. Such threaded adjustment may take the form of an adjustment screw that moves a carriage on which the focusing lens **254** translates.

In operation, laser light is supplied as by optical fiber or the like to the light receiving end **262** of the optical beam delivery assembly **130**. The laser light is then focused simultaneously with the fusion powder on the working focal point **270**. The energy of the laser light is sufficient to melt the fusion powder and, preferably, also at least some surface portion of the workpiece object to be welded and adjoined with the laser liquefied fusion powder. It is then possible to perform welds or other construction operations on metals or other surfaces susceptible to laser welding.

While the laser welding torch **100** can be used without fusion powder, the conjunctive

use of the fusion powder with the laser light **250** provides means by which repairs, seams and other constructive welding activities may be performed on metal objects or objects of other laser-susceptible materials.

In operation, the barb-to-pipe conduit **194** snugly and by means of friction fit receives an outlet connected to a supply of inert gas, such as the noble gas argon. Argon gas is then used to flood the plenum **186** as the front nozzle portion **184** is slightly offset from the interior of the nozzle gas cover **170** in order to provide a frustro-conic pathway for the inert gas to flow into the area between the nozzle **140** and the nozzle gas cover **170** and into the plenum **186**.

Inert gases are used in order to prevent the unintentional combination of molecules in the bleed and nozzle flow gas with the welding site. Such inert gases are known in the art and may be similar to those used in TIG (tungsten inert gas) welding (also known as GTAW or gas tungsten arc welding). Inert gases generally have the quality of not combining with other materials or molecules. Helium is one predominately-used inert gas and is a noble gas, as is argon. However, nitrogen may also be used as inert gas under some circumstances.

Additionally, if the welding site is to be doped or intentionally contaminated with substances beyond the substrate or the feed powder, the gas transport system may serve to deliver some doping compounds or molecules into the welding site. Some experimentation may be necessary with this embodiment, however, controlled oxidation, such as by the introduction of oxygen into the inert gas, may be desirable under such circumstances. Other gases could also be introduced into the inert gas flow in order to provide such intentional alteration of the chemical structure at the weld site.

By the application of non-reactive inert gas, the powder and working surface subject to the incoming laser light **250** is kept from oxidizing or otherwise combining with anything but the

surrounding material. Free oxygen or other gasses in the immediately adjacent environment close to the working focal point **270** are displaced by the inert gas. This allows a greater amount of control with respect to the welding of the workpiece object and/or the fusion powder. It also diminishes combustion, oxidation, and the likelihood thereof and provides for a better welding operation as only the materials sought to be welded are made liquid or soft by the energetic incoming laser light **250**.

By providing a hand-held powder-fed laser fusion welding torch as set forth herein, laser welding operations now become much easier for the aerospace mechanic or other metal worker. Additionally, with the availability of intense laser light via fiber optic cables as well as fusion powder in connection with the powder feed tubes **160**, the welding torch provides more useful means by which welding operations may be achieved.

Similar to that as shown in Figure 5, the proximity probe **220** may operate in conjunction with the laser source **280** in order to provide automatic switching operation according to the proximity of the workpiece **282**. In one embodiment, wiring is connected to the power connector **210**, and the proximity switch **222** then enables activation of the laser source **280** once sufficiently depressed into the proximity holder **224**.

Generally, the proximity switch **222** only enables activation and does not serve to actually activate the torch **100** unless it is the last element in the activation mechanism. The activation of the proximity switch **222** is a necessary, but not a sufficient, condition for the operation of the torch **100**. The activation of the proximity switch **222** is necessary because it must be activated in order in order for the torch **100** to operate. However, the proximity switch **222** is not a sufficient condition as it alone is not able to activate the torch **100**. A hand held trigger or the like (not shown) may also be used in conjunction with torch **100** in order to provide

additional control for the welder over the torch **100**.

Alternatively, and as shown in Figure 5, if the workpiece is electrically conductive, an electrical return path **284** may be established via an interlock control circuit **286**, which controls electrical supply via an electrical supply path **288**. With the closure of the electrical circuit via the safety probe **220**, electrical return path **284**, interlock control circuit **286**, and electrical supply path **288**, the interlock control circuit **286** will detect that the laser torch or laser torch **100** is in sufficient proximity to the workpiece **282** such that the laser torch **100** should be activated by the activation of the laser source **280**. The interlock control circuit **286** upon detecting a closed circuit path may enable activation of the laser source **280** so that laser light sufficient to perform welding operations may be transmitted via the laser emission path **288** to the laser torch **100**. Furthermore, the interlock control circuit **286** may also control a powder source **290** in the form of a powder feed assembly or the like.

The powder feed assembly **290** may be similar to that as is known in the art. Powder for the melt is transmitted as by pumping or the like to the nozzle **140** for transmission through the powder flow channels **152**. A source or reservoir for the alloy powder may be kept at a distance from the laser torch **100** and transmitted to the nozzle **140** by pressurized lines or the like.

Additionally, other types of sensors may be used in order to gauge the proximity of the torch **100**, and the focal point, from the welding substrate. Such sensors included non contact sensors that may use induction, capacitance, or optical characteristics in order to gauge the distance of the torch **100** from the welding substrate. The torch **100** is contemplating as using laser light having a wavelength of approximately 1.06 micrometers delivering energy sufficient to perform the welding activity set forth herein. The use of metal powder may subject a capacitive non-contact sensor to certain difficulties. Additionally, the heat and infrared energy

generated by the torch may also provide optical difficulties for an optical non-contact sensor. However, certain other qualities may be used in order to provide non-contact sensors and/or these difficulties may be overcome due to the characteristics of the particular non-contact sensor. Additionally, other sensors developed in the future may be applied to the torch **100** and may provide advantageous proximity sensing so that they may be easily or advantageously incorporated into the torch **100**.

Although not shown in Figure 5, the interlock control circuit may also control the supply of fusion powder as well as the flow of inert gas to the laser torch **100**.

The proximity probe or sensor **220** enhances operational safety through target discrimination and pointing constraints. It provides process control by defining or maintaining the correct working distance from the nozzle gas cover aperture **176** to the workpiece **282**. The proximity sensor **220** may either provide physical limits of working distance, or in the case of a closed loop control system, provide distance feedback for an automatic working distance compensation apparatus. Additional feedback may be provided by the proximity sensor regarding relative positioning between the weld site and the torch **100**. The proximity sensor **220** may provide audio and/or video feedback to the welder regarding such relative positioning. Moreover, the proximity sensor may provide sufficient feedback to allow the automatic adjustment of the laser light **250** and the powder flow.

The hand held laser welding torch **100** may include the integrated safety / proximity sensor **220** which has an electrically isolated contact probe **220** with a spring-loaded telescoping probe tip (available as an off the shelf component) **222** attached to the output end of the laser torch via the nozzle gas cover **170**. The sensor **220** may be gold plated for better conductance. This probe, along with the metallic surface of the workpiece **282**, forms an electrical path for a

laser process shutter control circuit **280**. In order to enable emission of the laser output, the safety sensor **220** must be both physically and electrically connected to the desired workpiece **282**. In so doing, the workpiece itself must be isolated from ground and insulated from adjacent metal components. The relationship of the position of the safety probe **220** while in contact with the workpiece **282** defines the direction of laser emission and ensures that the correct target has been selected. An electrical return path **284** must be provided from the workpiece **282** to the laser process shutter control circuit **280**. This is established through an electrical wire connection from the workpiece to the process control system. An alligator clip or equivalent clamp provides a suitable means for connecting to the workpiece.

Target discrimination is achieved by virtue of the required electrical contact as illustrated in Figure 5. Laser emission is prevented unless direct electrical contact between the safety sensor probe **220** and the workpiece **282** has been established.

Process control of the torch-to-workpiece working distance is also provided in this apparatus. The proximity sensor probe **220** includes a spring loaded, telescoping tip **222**. The range of movement of this tip defines the working distance as the operator manually follows the contours of the part. Alternate working distances and ranges of height tolerance are provided by a selection of interchangeable probe tips. Since the tip is easily replaced, new tips can be installed as needed due to normal wear and tear. Additionally, advances in laser-focusing and powder-feed technologies may allow the adjustment of the working focal point **270** according to the working distance detected by the tip **222**.

In an alternate approach, a point contact linear variable displacement transducer (LVDT) may be used in place of the basic spring-loaded probe described above. The LVDT probe provides a source of electrical feedback proportional to its displacement. This signal may be

used to actively control the laser and powder metal deposition systems to maintain a predetermined distance between the torch 100 and the workpiece 282 through a closed-loop feedback system interfaced with motorized lens and powder nozzle position actuators.

In another approach, one or more non-contact sensors may be attached to the welding torch 100 to provide safety discrimination and position sensing. The advantage of this approach lies in the high degree of flexibility and dexterity provided by a non-contact system. Access to a wider range of workpiece component shapes and configurations are possible compared with the point contact sensor.

Candidate sensors may be based on, but not necessarily limited to optical, capacitive, inductive or video technology. Combinations of more than one type of sensor may be necessary in order to provide the necessary degree of part discrimination and displacement resolution. The non-contact sensor technologies may be used with either manual operator or automatic closed loop control systems to maintain part distance requirements.

The hand held powder-fed laser fusion welding torch makes laser welding a manual process and no programming is necessary. It makes it easier to maneuver the laser output wand/torch into hard to reach places such as nozzles with curvatures. This feature allows for three-dimensional (3D) welding in random locations. Most existing laser welding systems are two dimensional (2D) and are limited due to automatic programming requirements with minimal x-y movements such that they cannot handle much variation between parts.

In the hand held powder-fed laser fusion welding torch, the laser beam and powder are focused outside of the nozzle. This helps to prevent the nozzle exit from clogging.

Shielding inert gas is used to protect the powder and substrate from contamination (i.e., oxidation) by removing oxygen and other reactive gases from the weld area. A lightweight

design makes the laser torch ergonomically correct, easy to use and maintain. YAG laser use with fiber optic cable creates the flexibility provided by using the hand held torch while delivering the laser beam to the weld area.

Proximity sensors allow welding to start at the focal point. The sensor is also used as a safety feature, to allow the laser beam start only when its focal point is close to the desired weld area. Inert carrier gas is used to deliver the powder to the focal point. This is to prevent any oxidation of the weld and powder. All details, or elements, of the nozzle assembly can be easily replaced. All components are easily screwed together.

In welding or using the laser torch **100**, a method is provided to manually laser powder fusion weld a workpiece in order to effect construction and/or repair. A hand held powder-fed laser fusion welding torch is provided that may be manually operated. In such manual operation, the torch generally enjoys significant degrees of spatial freedom so that the welder may dispose the torch in a variety and number of easily-achieved positions. In this way, the welder may conform his activities to the needs at hand and is preferably not limited by physical constraints of the laser torch.

The workpiece **282** may first be prepared as by solvent cleaning or the like to ensure that the workpiece is clean and ready for welding. Once prepared, the welding torch **100** is prepared for use with the source of laser light and source of fusion powder made ready. Depending on the construction of the welding torch **100**, the proximity sensor **220** may be brought into contact with the workpiece **282**. Once the welder is ready, a trigger (not shown) may be pressed to activate the welding torch **100** and the welding process upon the workpiece **282**. Laser light and powder flow are then delivered by the laser torch **100** to the work site and the welding process is performed upon the workpiece.

While the present invention has been described with reference to a preferred embodiment or to particular embodiments, it will be understood that various changes and additional variations may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention or the inventive concept thereof.

Particularly, the interchangeable nature of fasteners demands that the indication of one type of fastener or fastening herein is contemplated as enabling and disclosing all types of fasteners or fastenings that may be implemented to achieve all or part of the functionality of the disclosed type of fastener or fastening. For example, a bolt, screw, pin, rivet, or dowel may be interchangeable with one another as well as fastening as by welding. Likewise, other interchangeable elements, operations, or functions are contemplated as being similarly disclosed herein when one or more of such interchangeable or equivalent elements, operations, or functions are disclosed.

In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to particular embodiments disclosed herein for carrying it out, but that the invention includes all embodiments falling within the scope of the appended claims.